NAL PROPOSAL No. 0075

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A PROPOSAL TO SEARCH FOR FRACTIONALLY CHARGED QUARKS

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We propose to search for fractionally charged quarks, using one of the secondary beam channels in Area 2, by tuning the beam to a momentum higher than the primary proton beam momentum. The ionization and total energy of those particles transmitted by the channel will be measured using an array of scintillation counters followed by a total absorption counter.

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I. INTRODUCTION

We propose to search for fractionally charged quarks using one of the standard secondary beam channels in Area 2. The elements of the beam will be tuned to the highest energy, e.g. 200 GeV, and the primary proton energy will be set 5 to 20 percent lower than that of the secondary beam channel.

In a proton-nucleus interaction the simplest reactions which result in the production of quarks are:

$$P + "N" \rightarrow P + N' + q + \bar{q} \qquad (1)$$

$$\rightarrow N'' + 2q_1 + q_2 \qquad (2)$$

By tuning the beam to a momentum higher than the primary proton beam momentum, no particle with integral charge can pass through the entire length of the beam channel, unless it is scattered several times by collimator walls, magnet poles, or other elements in the beam channel. On the other hand, quarks with charge $|Q| = 2/3$ and momentum $\sim$140 GeV/c or charge $|Q| = 1/3$ and momentum $\sim$70 GeV/c would pass through the entire length of the channel. We propose to measure the ionization loss and total energy of those particles transmitted by the channel using an array of scintillation counters followed by an ionization calorimeter.

The technical advantages to the present scheme are:

1) The number of interactions per pulse can be as high as $\sim 10^{13}$ or more. This is very difficult to achieve at any location outside the main target station.

2) Integrally charged particles produced at the target will be eliminated almost completely by the secondary beam channel which already exists in the area. This reduces the background problem enormously without requiring additional magnets or detection equipment.

3) The present plans for Area 2 call for threshold gas Cerenkov counters at the end of each beam line. They are considered an integral part of the beam design. These Cerenkov counters give additional rejection against background from relativistic particles. Though these counters are not essential, if they exist, we will take advantage of them.

The physics justification for the experiment is quite obvious. The existence or non-existence of quarks is one of the most fundamental questions in particle physics at the present time. Many experiments have been performed with accelerators and cosmic rays.[1] Most experiments have obtained negative results and have given upper limits on the production cross section. Two experiments claim to have seen quarks in cosmic rays.[2] The experimental evidence is not convincing, however. Searches similar to that proposed here, have been made both at CERN and at Serpukhov.[3] The latest results at Serpukhov have set upper limits on the differential cross section for quark production:

$$7 \times 10^{-38}\ \mathrm{cm}^2/\mathrm{ster\ GeV}/c \quad \text{for Mass} \leq 5\ \mathrm{GeV}/c^2$$
$$\text{Charge} = -1/3$$

and

$$4 \times 10^{-38}\ \mathrm{cm}^2/\mathrm{ster\ GeV}/c \quad \text{for Mass} \leq 2.5\ \mathrm{GeV}/c^2$$
$$\text{Charge} = -2/3.$$

The experiment proposed here, taking advantage of the higher energy, will extend these limits to larger mass values. The largest quark mass attainable in our experiment, without using the Fermi motion of the target nucleus, is

$$\sim 8 \text{ GeV}/c^2 \text{ for the Reaction (1)}$$
$$\sim 6 \text{ GeV}/c^2 \text{ for the Reaction (2)}$$

if the proton energy is limited to 200 GeV. Since we plan to use a standard beam channel rather than setting up a special beam, our momentum and solid angle acceptance will be smaller than those of the CERN and Serpukhov experiments. However, the smaller acceptance of our system will be compensated by the higher intensity of the proton beam, resulting in a comparable cross section sensitivity. For instance, one event per hour in our experiment, assuming 2×10^{13} interacting protons, $\Delta p/p \approx 5\%$, and $\Delta\Omega \approx 5 \times 10^{-6}$ ster,

$$\frac{d^2\sigma}{dp\, d\Omega} \approx 6 \times 10^{-36}\ \text{cm}^2/\text{ster GeV}/c.$$

This seems to be sufficiently sensitive, since quarks are most likely produced "strongly" if the available energy is sufficient to produce them at all.

There is a proposal to look for quarks at NAL by an Ohio State-Indiana State-Kansas collaboration. Our technique is quite different, and is a small extension of the work involved in beam alignment and tuning that must be carried out in Area 2 by members of NAL staff.

II. EXPERIMENTAL ARRANGEMENT

The detection system to be used in this experiment is comprised of the following:

1) A beam telescope consisting of several scintillation counters distributed over the beam line. The first counter will be placed at a location where the singles counting rate of the counter is sufficiently low, e.g. $\lesssim 10^5$ per sec, that the accidental coincidences would not cause serious trouble. A rough estimate of the muon flux in the

shield indicates that this condition is met at ~600 feet downstream from the target. The last counter will be placed at the end of the beam, immediately followed by the ionization counters. The number and the thickness of these counters have to be kept minimum, since the quarks are expected to interact strongly with the material of the counters. In order to detect a particle with $|Q| = 1/3$ efficiently, a thickness of ~1/2 inch will be required. Several anti-coincidence counters must be added to reject particles scattered from the collimator walls, the magnet poles, etc. A coincidence (and anti-coincidence) of these counters will select only those particles which went through the beam channel without scattering. This requirement alone should give quite a strong rejection against background.

2) A threshold Cerenkov counter placed near the end of the beam. This, in anti-mode, will give us further rejection against fast particles, particularly pions. A semi-permanent installation of such counters in the beam has been suggested by W. Baker and is being studied by the members of the Experimental Facilities group. For example, the particular arrangement of counters suggested by Baker is expected to reject pions against anti-protons by a factor of 10^{-9} at 150 GeV/c. This would be a powerful addition to our system. Since the counters will be operated below atmospheric pressure their presence would not add excessive material to the beam line.

3) Ionization Counters. They are a set of 8 small scintillation counters, $\lesssim 3''$ in diameter and 1"-2" in thickness, placed adjacent to the last element of the telescope counters. They have to be protected, by a set of anti-counters, against particles passing near their edges. The output of these counters will be displayed on an oscilloscope.

The oscilloscope will be triggered by an acceptable signal from the telescope (and the Cerenkov counter) and the display will be recorded by a camera. These counters have to be carefully calibrated by a beam of singly charged particles, during the test run, and checked by a light source with an attenuator for linearity of response.

4) A total absorption counter. If the above arrangement does indeed result in a non-zero trigger rate, a total absorption counter can be added to the system to measure roughly the energy of the accepted particles and establish whether or not they are in the appropriate energy range for quarks transmitted by the beam channel. This counter would reject any continuous background of hadrons, and provide a strong rejection against muons. An example of total absorption counter is that described by Jones[4] and consists of a ~35 layer iron-scintillator sandwich, 2" thick iron and 1/2" thick scintillator, 30" in diameter. The energy resolution is expected to be 3-10% at 200 GeV. This corresponds to 5-15% at 140 GeV and 10-30% at 70 GeV. A system like this one seems to be adequate for our purposes, and can be calibrated in place by appropriate tuning of the beam.

This experiment can be done with either one of the three high energy charged beams in Area 2. The 3.5 mrad beam has the advantage of large solid angle acceptance and large momentum acceptance. On the other hand, the transverse momentum of the particle coming into this channel is higher than in the other beams. For instance a particle with a momentum of 140 GeV/c must have a transverse momentum of 0.5 GeV/c. If the production mechanism is such that small transverse momenta are strongly favored, it would be advantageous to use the 1.75 mrad (diffracted proton) beam. Another possible advantage of the 1.75 mrad beam is the fact that this beam could be tuned to a higher energy than the other two, since none of the bending magnets are run above 10 kg at 200 GeV/c.

We request approximately 100 hours of testing and 100 hours of data taking time. In the test period we will tune the beam for lower energy, letting a small amount of negative pions (or protons) through the channel, and calibrate our detectors with single charged particles. We expect to take data with both negative and positive beams. One event in 50 hours of the data taking run corresponds to a differential production cross section of $\sim 10^{-37}$ cm^2/ster GeV/c.

III. IMPLEMENTATION

With the exception of the total absorption counter the equipments to be used in this experiment are either standard, i.e. they should exist when the area becomes available for an experiment, or simple. The beam telescope counters and the ionization counters can be built in a short time. All the necessary parts, scintillators, phototubes, etc., already exist in the Physics Research Section at NAL. This also applies to the total absorption counter, although it may require some developmental work. If the proposal is accepted, we would request a few thousand dollars of financial support and three technician-months of manpower support from our research section for the development work on the total absorption counter. We also need a multi-trace oscilloscope, pulse height analyzer, and some standard electronics circuits. They all exist in our equipment pool.

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